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DØ

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B-Physics Results from D0

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Abstract

We report on preliminary measurements of the inclusive single muon and dimuon cross sections in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV using the D0 detector at the Fermilab collider. From these results, we extract the cross section for b -quark production for the kinematic range $|y_b| < 1.0$ and $6 < p_t^b < 50$ GeV/c. We also report measurements on the J/ψ and Υ production cross sections, sources of J/ψ production, and correlations between muons in dimuon events.

1. Introduction

The D0 experiment at the Fermilab Tevatron has measured the inclusive single muon and dimuon cross sections for $|\eta_\mu| < 0.8$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV using data taken during the 1992-93 collider run. The b -quark cross section is extracted using these measurements and found to be in good agreement with next-to-leading order QCD predictions. The inclusive J/ψ and Υ cross sections in the central region have also been measured and sources of J/ψ production are discussed.

The D0 detector has been described elsewhere [1]. It consists of inner tracking chambers used to measure the primary vertex and to help identify electrons and muons, uranium-liquid argon calorimeters to detect electrons, photons and jets, and iron toroids and drift chambers to detect muons. The combined calorimeter plus toroid thickness varies from about 14λ in the central region to 19λ in the end. This thickness reduces the punchthrough backgrounds to less than 1% of prompt muon production and also allows for

clean muon identification within hadronic jets. Muon momentum is measured using the toroid and has a resolution of $\sigma(p)/p = 0.18(p - 2)/2 \oplus 0.008p$ (p in GeV/c).

2. Measurement of the b -quark Production Cross Section

We have measured b -quark production cross section using the semileptonic decays $b \rightarrow \mu + X$ and $b\bar{b} \rightarrow \mu\mu + X$. For this paper, only results from the central region with $|\eta_\mu| < 0.8$ are presented. Events were collected using three different triggers, giving a single muon, a muon plus jet, and a dimuon data sample. Each trigger required a level 0 trigger which indicated that an inelastic collision had occurred. Level 1 muon triggers used 60 cm wide hodoscopic elements formed from the muon drift chambers, and required 2 or 3 layers of chambers to have hits consistent with a muon produced in the interaction region. The minimum energy of muons exiting the toroid is about 3.2 GeV and the level 1 muon trigger became fully efficient at 5 GeV. At level 2, muons and jets are identified using a software filter composed of the initial part of the offline reconstruction. Single muon

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triggers require one or more level 1 and level 2 muon triggers while the dimuon triggers require two or more at each level. The muon plus jet trigger also required calorimeter energy in a level 1 trigger tower of 0.2 by 0.2 $\Delta\eta - \Delta\phi$ to be ≥ 3 GeV.

Good muons were selected offline by requiring each muon to have hits in all three layers of the muon system for the single muon cross section analyses (this requirement is relaxed by one for the dimuon cross section). Additionally each muon was required to have at least 1 GeV of associated calorimeter energy, possess a matching track in the central tracking chamber, point back to the interaction vertex in the bend and non-bend views, and traverse a minimum field integral of 0.6 GeV/c in the toroids.

All muons were required to have $|\eta^\mu| < 0.8$. Additional kinematic cuts applied were $3.5 < p_t^\mu < 60$ GeV/c for the single muon cross section and $p_t^\mu > 6.0$ GeV/c and $E_t^{jet} > 12$ GeV for the muon plus jets cross section. Dimuons were required to have $4 < p_t^\mu < 25$ GeV/c and mass $6 < M_{\mu\mu} < 35$ GeV/c².

Cosmic ray contamination was estimated by fitting the crossing time distribution in the muon chambers (called floating T0) to distributions of known beam produced muons and cosmic rays. In all analyses the remaining cosmic ray contamination is approximately 10%. After all cuts the number of single muon events is 19000 from 93 nb⁻¹ of data. For muons plus jets the corresponding numbers are 4300 events from 197 nb⁻¹ of data. For dimuons, 550 events from 6.4 pb⁻¹ of data passed all cuts.

Trigger and offline selection efficiencies were determined by passing Monte Carlo events through the full D0 detector, trigger simulation, and reconstruction packages. In all cases the efficiencies were cross checked using appropriate data samples.

The resulting single muon cross section is shown in Figure 1. Also shown are the ISAJET Monte Carlo predictions for the predominant processes giving single muons. The sum of all contributions is in good agreement with the data.

The resulting dimuon cross section plotted as a function of the highest p_t^μ of the pair is shown in Figure 2. Also shown are the ISAJET Monte Carlo predictions for the predominant processes giving dimuons. The sum of all contributions is again in good agreement with the data.

In order to extract the b -quark cross section one must estimate that fraction of the inclusive muon or dimuon spectrum coming from b -quark decays. The b -quark decay fraction is found using the ISAJET results for the known background contributions to b -quark production. For the single muon and muon plus jets analyses, the b -quark fraction was cross checked by fitting the p_t^{rel} distribution in the data as the sum

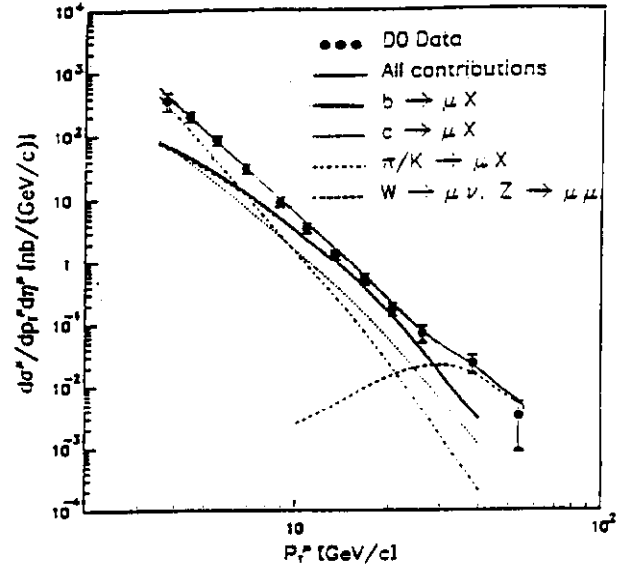


Figure 1. The single muon cross section vs. p_t^μ for muons with $|\eta| < 0.8$.

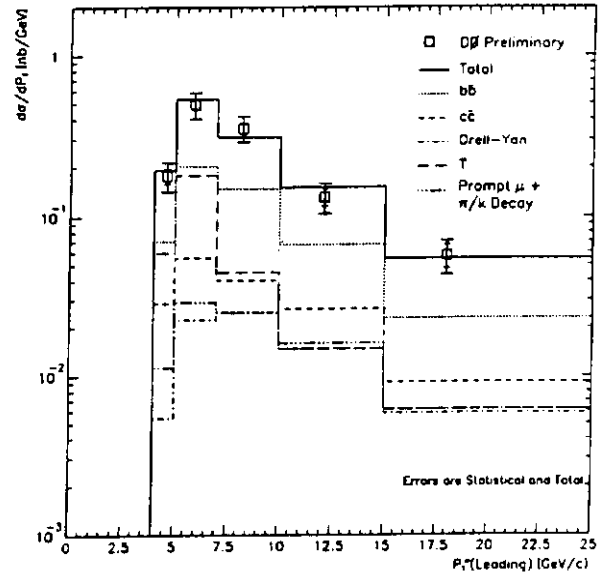


Figure 2. The dimuon cross section vs. the highest p_t^μ of the pair, for muons with $|\eta| < 0.8$.

of p_t^{rel} distributions from b -quark decay and c -quark plus π/K decay. The quantity p_t^{rel} is the transverse momentum of the muon relative to the associated jet axis where the jet momentum also includes the muon momentum. The b -quark fraction found with this fitting procedure is in good agreement with the b -quark fraction determined via Monte Carlo alone. Once the fractions of the single muon and dimuon inclusive cross sections coming from b -quark decay is determined, the integrated inclusive b -quark cross section can be extracted following the method of UA1 and CDF in order to facilitate

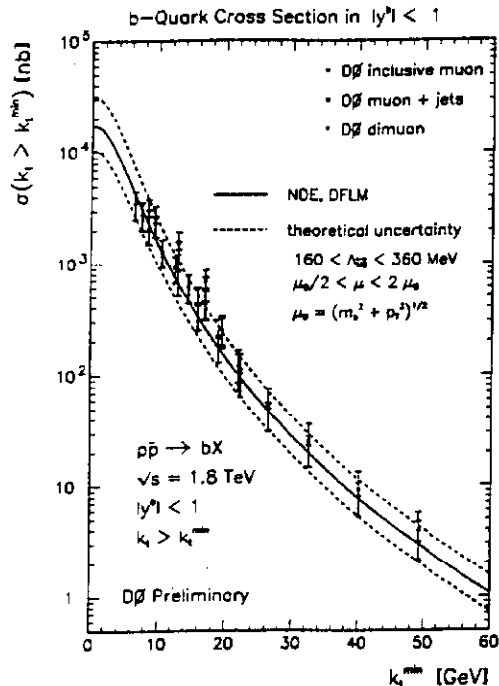


Figure 3. The b -quark cross section vs. k_t^{\min} for the single muon, single muon plus jet, and dimuon analyses.

comparison [2, 3]. The resulting b -quark cross section is plotted in Figure 3 from the inclusive muon, muon plus jet, and dimuon cross section data. The results are consistent with the next-to-leading order (NLO) QCD calculations of Nason *et al.* [4].

3. Inclusive J/ψ Cross Section and Production Mechanisms

To select J/ψ candidates, each muon was required to pass similar track quality criteria as in the dimuon cross section analysis described above. The dimuon was required to have oppositely signed muons, invariant mass in the range $2 < M^{\mu\mu} < 4.0$ GeV/ c^2 , and $|\eta_\psi| < 0.6$. The number of J/ψ after all cuts was estimated by fitting the invariant dimuon mass distribution to the sum of a Gaussian centered at the J/ψ mass and a polynomial background (consisting mostly of sequential b -quark decays). The total number of J/ψ given by the fit was 450 ± 20 from data runs having a total integrated luminosity of 7.2 pb $^{-1}$. The overall J/ψ detection efficiency is a combination of trigger and offline efficiencies, and was determined using complete detector and trigger simulations. The number of J/ψ 's in each p_t^ψ bin was determined from the fit described above. The inclusive cross section times branching ratio shown in Figure 4 was obtained by dividing the data bin by bin by the J/ψ detection efficiency and the integrated luminosity. The D0 data points are in good agreement with the CDF data [5]. Also shown are the

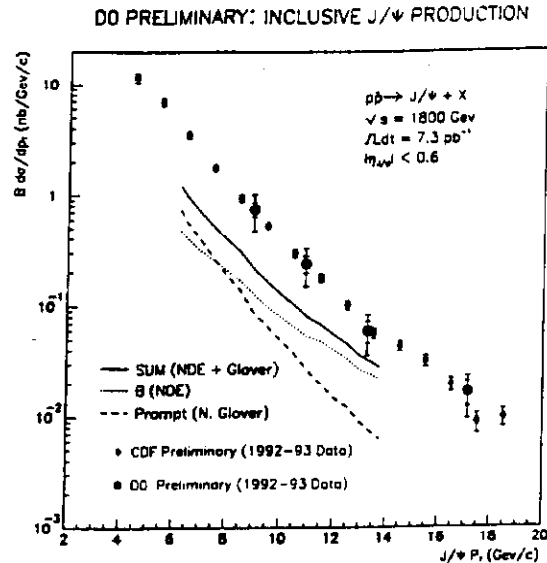


Figure 4. Inclusive J/ψ cross section a function of p_t^ψ .

theoretical estimates for J/ψ production from b -quark decay and direct charmonium production [6, 7]. The measured inclusive ψ cross section lies well above the prediction for the sum of these two processes, indicating contributions from further processes not modelled by the theory. Additional diagrams such as gluon and charm fragmentation into J/ψ and χ_c [8] have been proposed to account for this discrepancy.

3.1. Fraction of J/ψ from b -quark decay.

The fraction of J/ψ 's from b -quark decay was estimated using trimuon events. A fit was made to the invariant mass spectrum of the dimuon sample in the range $1 < M^{\mu\mu} < 5$ GeV/ c^2 , as the sum of signal (J/ψ) and background (sequential decays) distributions. Next the dimuon invariant mass is formed using trimuon events (J/ψ plus muon (b -quark) tag). Using the shapes obtained from fitting the dimuon sample, the identical fit was performed on the trimuon events, and the relative proportions of signal and background extracted. The number of J/ψ predicted from the fit is $2.5^{+3.3}_{-2.5}$. ISAJET Monte Carlo studies were then used to determine the fraction of J/ψ plus muon tag events in inclusive J/ψ events from $b\bar{b}$ production. From this, an upper limit for the J/ψ fraction from b -quark decay at the 95% CL was determined to be 50%.

3.2. Fraction of J/ψ from direct charmonium.

J/ψ 's from direct charmonium production arise primarily through the decay of χ_c . The muons from χ_c are expected to be isolated, and are accompanied by a low E_t photon. Isolated J/ψ 's were chosen from the J/ψ sam-

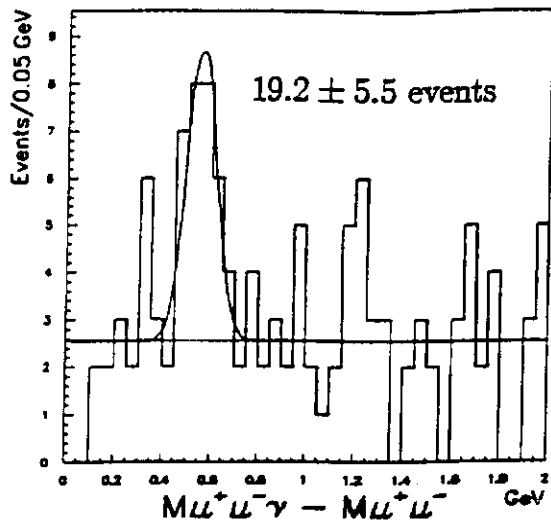


Figure 5. $M_{\mu\mu\gamma} - M_{\mu\mu}$ for the $\chi_c \rightarrow J/\psi X$ sample.

ple by requiring no jet be found in a cone of $\Delta r < 1.0$ in $\eta - \phi$ space about each muon. Events with photons were tagged by requiring the presence in the event of an electromagnetic calorimeter cluster of energy $E_\gamma > 0.6$ GeV. Figure 5 shows the distribution of mass difference, $M^{\mu\mu\gamma} - M^{\mu\mu}$, with a peak at roughly 0.55 GeV. The number of χ_c 's predicted from the fit (after background subtraction) is 19.2 ± 5.5 . Dividing this number by the photon detection efficiency (0.21) and isolation efficiency (0.33) gives the fraction of J/ψ with $p_t > 8$ GeV/c and $|\eta| < 0.6$ from χ_c decay as $0.41 \pm 0.14 \pm 0.10$. This is in good agreement with the CDF result [9] for $p_t^\psi > 6$ GeV/c and $|\eta^\psi| < 0.5$.

4. $b\bar{b}$ Correlations

The angular separation of the leptons from $b\bar{b}$ decay is related to the particular mechanism involved in producing the b 's. Figure 6 shows the distributions in azimuthal opening angle between the muons in $b\bar{b}$ decay for the leading order process of flavor creation compared to two NLO diagrams, gluon splitting and flavor excitation. Here we adopt the phenomenological model of ISAJET. Measurements of angular correlations of the leptons can be used to separate leading from NLO contributions to the $b\bar{b}$ cross section, and test the QCD predictions for these contributions.

The data and selection criteria for this measurement were the same as for the $b\bar{b}$ cross section measurement. ISAJET Monte Carlo was used to provide shapes to fit the LO and NLO contributions to the dimuon cross section as a function of $\Delta\phi$ of the muons. It was also used to estimate the b fraction in each $\Delta\phi$ bin. Figure

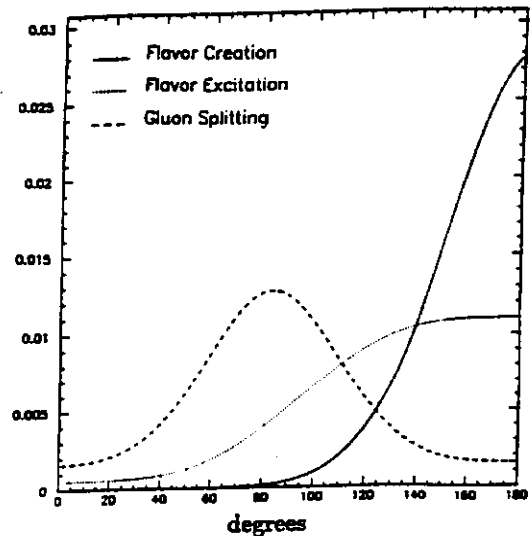


Figure 6. Azimuthal opening angle of muons from $b\bar{b}$ decay for LO and NLO production mechanisms.

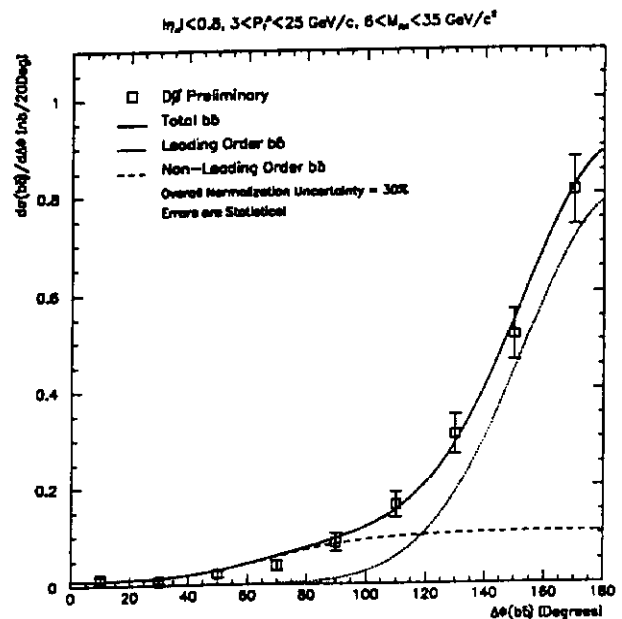


Figure 7. $b\bar{b}$ cross section as a function of azimuthal opening angle of the muons. Curves are ISAJET predictions for LO and NLO contributions.

7 shows the $b\bar{b}$ cross section as function of the dimuon opening angle fit to the ISAJET predictions for the LO and NLO (sum of flavor excitation and gluon splitting) contributions. The fit predicts $71 \pm 8\%$ from LO and $29 \pm 5\%$ from NLO processes, in good agreement with the fractions in ISAJET of $71 \pm 1\%$ and $29 \pm 1\%$.

5. Inclusive Upsilon cross section

The data sample for the Υ analysis was selected from the same data as for the dimuon analyses described

above. Since muons from Υ decay are expected to be isolated, at least one of the muons in each event was required to satisfy an isolation cut defined as the calorimeter energy deposited in a cone of $r = 0.2$ in $\eta - \phi$ space about the muon, minus the energy expected for minimum ionizing particle (divided by the energy uncertainty). A simultaneous maximum likelihood fit to three distributions: dimuon mass, energy deposition in a wide cone of $r = 0.6$ minus the energy in cone of $r = 0.2$ about the muon, and floating T0 (defined in section 3), was used to extract the number of Υ 's from the background (QCD, Drell-Yan, and cosmic rays). The shapes used in the fit were derived from appropriate data samples, and in the case of the mass distribution, from Monte Carlo. The result of this fit is shown in Figure 8. The number of Υ 's predicted in the sample from this fit was 95^{+15}_{-14} . Correcting for the acceptance, the offline cuts, and the trigger efficiency, and the integrated luminosity of the sample, the total cross section times branching fraction to muons was calculated to be:

$$\sigma \cdot B(\Upsilon \rightarrow \mu\mu) = (9.5 \pm 1.1(stat) \pm 4.3(sys)) \times 10^3 pb \quad (1)$$

Assuming the $\Upsilon(1S) : \Upsilon(2S)$ ratio to be 2 to 1, and using published Particle Data Group branching fractions [10, 11] the total branching fraction was calculated to be $2.09 \pm 0.19\%$. Using this figure, the total Υ production cross section was calculated to be

$$\sigma_{\Upsilon} = (4.5 \pm 0.5(stat) \pm 2.1(sys)) \times 10^5 pb \quad (2)$$

The leading order theoretical prediction for the total cross section [12] is $(1.5 \pm 0.5) \times 10^5 pb$, a 2σ deviation from the D0 result.

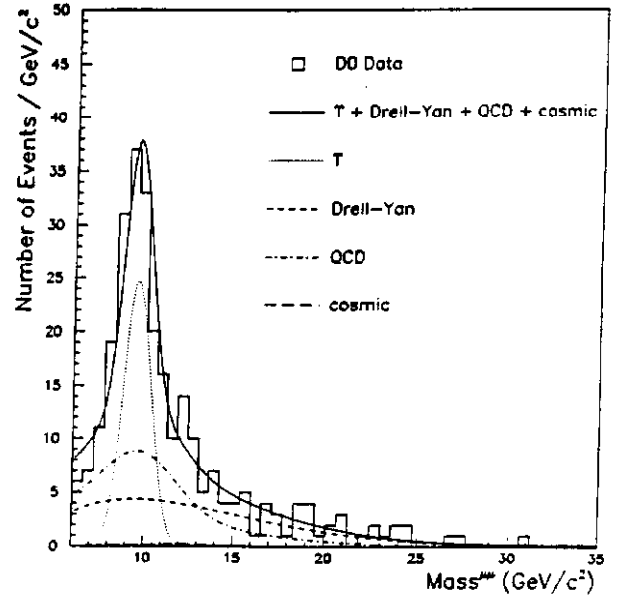


Figure 8. Result of simultaneous fit to the mass distribution in the Υ sample. Data is shown as a histogram. Curves are Monte Carlo signal and background (data) contributions.

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